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# The vulnerability of hydroelectric generation in the Northeast of Brazil: The environmental and business risks for CHESF

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ABSTRACT

The main objective of this study is to identify how global climate change may affect the internal and external variables of enterprises, and how strategic planning could include responses to potential performance threats. A case study was prepared using data from the São Francisco Hydroelectric Company (CHESF), the largest hydroelectric power generator in Brazil's Northeast region. It is essential to understand how the leading energy company in the region is preparing to address these problems involving economic impacts resulting from the environmental effects of climate change. Two prospective methodologies were used to select the variables and construct a SWOT matrix, and their respective scenarios: A Panel of Experts and the Delphi Method. The methodologies used allow for four (4) distinct scenarios to be inferred for CHESF up until 2050: Development, Growth, Survival and Decline. The analyses of these scenarios concluded that CHESF's main risk from climate change is the possible reduction of water flow and reservoir levels, which could threaten energy security throughout the country if certain preventative adaptations to climate change are not implemented.



**Contents**



## 1. Introduction

The possibility of an event occurring that will cause a shortage of hydroelectric power is a major concern for businesses and

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[1] The findings, interpretations, and conclusions of this paper are the authors' own and should not be attributed to São Francisco Hydroelectric Company and any Brazilian authority member.

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consumers, especially to those located in areas where the availability of water is limited. In the face of climate change, the way in which companies perceive the risk of electricity shortages can be a determining factor in the anticipated response actions that will be taken to ensure that supplies are not interrupted.

These actions involve adaptation and changes in strategic planning to reduce the vulnerabilities of concerned parties. Vulnerability and sustainability are interrelated concepts. The term vulnerability denotes a limit where a person or system may be affected to the point where sustainability may be compromised, while sustainability is the ability to maintain a system in a given condition [1]. From a business standpoint, sustainability assumes environmental, social and economic dimensions. Business vulnerability results from negative impacts that can affect their situation and their ability to react to and overcome potential obstacles.

The objective of this study is to identify how global climate change - GCCs could affect hydroelectric power companies' internal and external factors, and how they could include responses to potential social, economic and operational performance risks in their strategic planning. Date gathered included expert opinions, a review of the literature and information provided by the company and government agencies. The empirical study was developed using SWOT methodology to construct scenarios and identify internal and external variables that could offer options for corporate decision-making, in advance of GCCs predicted to occur by 2050.

## 2. The context of the case study

A case study was compiled using data from the largest hydroelectric power generator in Brazil, to identify the possible impact of GCCs on selected internal and external variables observed in the current context and those predicted for 2050. It was important to study the leading power generation company in the Northeast of Brazil as it prepares to confront these economic impact issues arising from the impacts of climate changes on the environment.

The supply of electricity for the Northeast region comes predominantly from the São Francisco Hydroelectric Company (CHESF), which began operations in 1948 and currently has the biggest installed capacity in the country (10,615 MW). More than 97% of its energy production comes from hydroelectric plants. Power transmission is accomplished by a system composed of 18,588 km of high-tension power lines.

There is an expansion trend in the regional consumer market in residential, as well as industrial and commercial units. CHESF is concerned with finding alternatives to meet the demand, while also preventing potential competitors from invading its service territory. In this regard, CHESF's most likely competitors in the power generation business are companies from other regions that can access its market through auctions conducted by the Brazilian National Electric Energy Agency (ANEEL). However, in the short and medium term, none of these companies have enough capacity to service the Northeast region without prejudice to their own customers. Another barrier to entry is the cost of tariff of energy, as long distance power transmission costs can be burdensome.

The proximity of consumption centers is an important competitive advantage, which could only be threatened by the establishment of new businesses in the region. In this case, as hydroelectric plants are almost at their limits, other fuels will need to be used, for example, thermal or nuclear power generation. However, current energy policy for meeting environmental policy targets for reducing greenhouse gas (GHG) emissions would seem to seek to avoid the installation of new thermoelectric power plants. Likewise, the deployment of a thermonuclear plant is not on the Brazilian planning horizon through 2019.

**Table 1**
Evolution of energy sold – CHESF – 2006–2009 (GW h).
**Source**: Authors based on data from Companhia Hidrelétrica do São Francisco (CHESF) [24,25].

| PERIOD | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|
| Energy sales (GW h) | 46,904 | 49,596 | 50,692 | 46,409 |

The Brazilian federal government's policy to attract private capital to increase investments in the energy sector, includes minority participation of state-owned enterprises in various projects, in partnership with the private sector. This corporate framework, with private control, should give greater flexibility and freedom in management of these new businesses.

CHESF has minority interests in some of these associations in the states of Mato Grosso and Rondônia. These projects evidence what can be a company strategy: the expansion of supply to other regions of Brazil, notably in the North region.

Operationally, the company generated 49,956 GW h in 2009, as opposed to 41,239 GW h in 2008, which represents an increase of 21.1%. But in the 2006–2009 period, the evolution of the energy generated, reflects a reduction of 9.5%. Despite a reduction in the amount of generated energy over the past four years, consumption increased by 10.3% during the same period.

The mismatch between energy generated and energy consumed was filled by importing (or transferring) from other regions that are integrated into the national system. In 2006, 2741 GW h were transferred, rising to 11,672 GW h in 2009, i.e., these transfers have increased by 325.7%.

Changes in the quantity of electricity sold shown in Table 1, reveal a 1% drop in the 2006–2009 period, whose highlight is an increase in 2008, due to the extraordinary market for energy in the short-term market (spot market). According to Relevant Data from the ONS in 2008, when comparing 2008 with 2007, the drought precipitated by the La Niña weather phenomenon caused a 28.48% reduction in hydroelectric power generation and a 312.69% increase in thermal generation in the Northeast.

Revenues from CHESF in the period 2005 to 2009 had a Compound Annual Growth Rate (CAGR) of 4.85%. The price of energy sold is set by the ANEEL, through an auction for the supply of periodically-adjusted, long-term contracts.

These auctions occur in the Regulated Contracting Environment (RCE), designed to serve captive consumers who are allowed to buy energy only from the distributor in whose network they are connected. The RCE has become the market where all of Brazil's generators offer energy to serve the pool of distributors, which operates on a low-bid basis unlike energy from new or existing source.[2]

As a benefit to consumers, one of the pillars of the energy policy in place today is the possibility of the occurrence of a discount-rate ceiling, set by ANEEL before the auctions. There is nothing to suggest in the government's plans that this regulatory strategy will be changed. Therefore, it can be assumed that fees, for both the sale price of energy and the use of the transmission network, will continue to be defined based on these rules.

Power transmission activities contributed to the results for CHESF, with guaranteed annual income from previously signed contracts, which legally obligate it to provide access to assets that are part of the basic transmission system network.

[2] New energy is energy for which charges include the costs of expansion (construction); existing energy is that for which those charges do not have this cost component.

The company's Fixed Assets are US$ 8174.7 million and in 2009, new investments totaling US$ 366.4 million were made for the expansion and modernization of production capacity. In the 2005 to 2009 period, the CAGR for investments was (+) 8.18%, but for the 2004–2008 period it was negative, with a reduction of (−) 1.2%.

The volume of investments is crucial to energy security, which requires a reliable supply system and guaranteed supply. In the case of CHESF, there is an indisputable need for it to strengthen its facilities and prevent energy supply disruptions, as had occurred in early 2010 and 2011, when at least eight states in the region went dark as a result of failures in the transmission system.

Reliability can be achieved with the planned investments for the coming year. Guaranteeing supply bears a greater degree of uncertainty because it depends on water resources, a natural input upon which no one has control.

Further for investment, it should be noted that if the volume of investment is insufficient to ensure the expansion and maintenance of the system; the company may have its revenues reduced and be forced to pay fines for legal noncompliance and possible breaches of contract.

Accordingly, the plan anticipates increased investment in assets, for operating improvements in generation and transmission systems, which are critical if CHESF is to maintain continuity and availability levels sufficient to satisfy demand [2].

These assets have allowed the company to produce positive results in recent years, with net income increasing at a 9.26% CAGR for the 2005 to 2009 period.

The Federal Government holds a controlling interest in Centrais Elétricas Brasileiras S.A. (ELETROBRAS), which owns 99.45% of the capital stock of CHESF, currently one of the most profitable companies in the ELETROBRAS System (composed of seven companies that produce hydroelectric power). In this sense, it is worth noting that it contributes favorably with a primary surplus to public accounts, assuming a strategic position in government planning.[3]

According to Gobetti [3], government-controlled companies are responsible for more than half of the efforts needed to achieve fiscal adjustment goals, which reveals their key role in the current macroeconomic policy framework. Between 1999 and 2006, the direct and indirect contribution of these companies to the primary surplus totaled US$ 90 billion, more than all of the revenue produced from the sale of state enterprises between 1991 and 2002, the period during which the privatization process took place.

Dividends distributed to CHESF shareholders were 100% of 2009 net income and 51.4% of net income for 2008. The obvious option to transfer most of the annual results to the shareholders indicates that management returned maximum value to the shareholder, focusing on earnings per share, one of the management pillars adopted by the competitive Brazilian electricity market and by ELETROBRAS.

CHESF manages its assets independently but must take into account, however, the strategic planning guidelines from its holding company. According to ELETROBRAS [4], one of its structuring principles ensures that its subsidiaries have their own identity and autonomy within the guidelines of the holding company.

The company profile can be analyzed by various profitability indexes, among which standouts include Return on Assets (ROA) and Return on Equity (ROE), whose values appear in Table 2 in comparison with two other ELETROBRAS-controlled companies: Furnas Centrais S.A (FURNAS) and Centrais Elétricas do Norte do Brasil (ELETRONORTE).

FURNAS is the second-largest Brazilian company in terms of installed capacity (9456 MW) and provides electricity primarily to the Southeast Region of Brazil. ELETRONORTE ranks third in installed capacity (9256 MW) and operates primarily in the North region.

The intention here is not to evaluate the performance of these companies, but only to compare some of their profitability indexes, underscoring the differences with CHESF, whose ratios (ROE and ROA) are shown in Table 2.

Return on Assets (ROA), which relates net income (net profit) to total assets, indicates profitability achieved by the company in view of total investments made. In CHESF's case, this return has been showing an improving trend, from 3.5% in 2007 to 4% in 2009, on average, the best performance among the three companies.

The Return on Equity (ROE) shows the premium that investors have obtained in relation to their investments in the company. In 2007, CHESF's ROE was 5.8% and, in 2009, it stood at 5.1%. In this ratio, as well, CHESF obtained better average results than the other two ELETROBRAS System companies.

Despite CHESF's prominent position, the rates represented by the two ratios (ROA and ROE) show that returns have not been very significant, especially when compared with the average interest rate paid on loans, which in 2009 ranged between 7.2% and 12%.

According to Silva [5], as long as the ROA was less than the cost of debt, there is no advantage in using the resources of third parties. This claim stems from the fact that third party resources (debts) are not adequately contributing to the increase of the company's profits, i.e., there is no financial leverage.

It would appear that an additional effort should be made to achieve a more appropriate result for these ratios, to contribute more favorably to the development plans of the ELETROBRAS System.

### 2.1. Electric power in the Northeast region: History and forecasts

In the operation of Brazil's electrical system, four interdependent subsystems supply almost all of domestic demand: South, Southeast/Center-West, Northeast and North, through what is known as the National Interconnected System (Sistema Interligado Nacional, SIN), under the coordination and control of the National Electric System Operator (Operador Nacional do Sistema Elétrico, ONS). In total, 444,438 GW h were produced in Brazil in 2009, of which 414,542 GW h were generated by hydroelectric plants.

The São Francisco River Basin, where the main CHESF plants are located, is the second-largest energy producer (51,985.1 GW h in 2009) and considered the most vulnerable to GCCs in the Brazilian territory [6].

The Northeast region's hydrological vulnerability can be understood by various dimensions on the climate change forecast horizon. With regard to climate, if droughts intensify and

**Table 2**
Profitability indexes: CHESF/FURNAS/ELETRONORTE (2007–2009).
**Source:** Authors.

| Companies | ROA—return on assets | | | ROE- return on equity | | |
|---|---|---|---|---|---|---|
| | 2007 (%) | 2008 (%) | 2009 (%) | 2007 (%) | 2008 (%) | 2009 (%) |
| **CHESF** | 3.50 | 7.70 | 4.00 | 5.80 | 12.70 | 5.10 |
| **FURNAS** | 3.64 | 2.24 | −0.65 | 5.30 | 3.44 | −0.94 |
| **ELETRONORTE** | −2.60 | −13.60 | 1.70 | 5.92 | −28.15 | 3.06 |

[3] Primary surplus: the difference between the flow of revenues and expenses, excluding those of a financial aspect.

temperatures increase, the process of desertification forecast for a large part of this region may accelerate. Additionally river flows may become insufficient for all of their current uses.

From an economic standpoint, some activities, such as agriculture and hydroelectric power generation, could no longer be viable, which would affect the pace of development planned for the region. The social dimension is more complex as poverty indexes are already in sharp contrast.[4] The region's social and economic inequalities cannot be ascribed solely to climate vulnerabilities because, according to Carvalho and Egler [8], political considerations and socioeconomic history have had a significant impact on the development of the region.

The region's characteristics indicate that there is need for improvement and adaptation of existing policies, so that economic, social and environmental dimensions are considered as part of regional energy planning.

The estimated load for the coming years cannot be fully met by hydroelectric power expansion, as the possibility of exploring new hydroelectric plant development tends to decrease as the remaining potential become subject to environmental and economic constraints arising from the advance of the electric frontier to preserved forest areas in the Amazon.

In this context, long-term planning is considering the use of other sources of alternative and renewable energy, such as wind, photovoltaic and biomass, favoring the technological route that contributes the most to reducing greenhouse gas (GHG) emissions. An increase in the supply of nuclear energy cannot be ruled out, however, even in the face of the chilling effect of the radiation leaks that occurred at the beginning of 2011 in Fukushima, Japan on such discussions.

The Northeast region is not self-sufficient—it does not produce all the electricity it consumes. The region depends on an exchange with other submarkets, especially with the North Sub-system.

Consumption estimates and the corresponding electricity production are prepared by the Energy Planning Company (EPE) and distributed through the 10-Year Energy Plan (EDP) for the period 2010–2019 and the National Energy Plan (NEP), with forecasts to 2030.

Preliminarily, it is worth mentioning that the long-term energy planning in Brazil still does not take into account potential impacts of climate change in the Brazilian energy system [6].

NEP is establishing the boundary conditions for the trajectory of the main variables related to the electricity sector. In this sense, four scenarios (A1, B1, B2 and C) for the horizon 2030 were prepared. The Ten-Year Energy Plan (PDE 2010–2019) uses the B1 scenario as a reference and makes estimates based on their assumptions, in brief:

– *Scenario B1:* economic growth (4.1%), difficulty in the approval of microeconomic reforms, bottlenecks in infrastructure, in winning effort by international markets, capital constraints for Research, development below the level of more developed countries, limited credit; conflict between growth and exploitation of natural resources, social and regional inequality, partial redistribution of income, electricity consumption grows 4.3% annually.

The PDE provides forecasts in more detail, showing more clearly the technological, economic, social and environmental paths that will be followed in this decade.

Some of the variables of national energy policy, adopted in the preparation of this scenario, appear on Table 3 below, in which are highlighted four indexes considered relevant by the federal government.

**Table 3**
Estimated annual growth rate—the Northeast and Brazil.
**Source:** own elaboration with data from the PDE 2019 [26].

| Period/ indexes | GDP (%)[a] | Population (%) | Load (consumption) (%) | Installed capacity (%) |
|---|---|---|---|---|
| Brazil | | | | |
| 2010–2014 | 5.20 | 0.80 | 5.80 | 5.40 |
| 2010–2019 | 4.00 | 0.70 | 5.30 | 4.80 |
| Northeast | | | | |
| 2010–2014 | 5.20 | 0.70 | 5.90 | 6.50 |
| 2010–2019 | 4.00 | 0.70 | 5.40 | 6.11 |

[a] Used the same rate of GDP to the Northeast of Brazil.

Based on these estimates, the energy load (consumption + losses) in the Northeast and Brazil should grow at rates higher than the GDP growth. Table 3 also shows, that the increase in installed capacity in the Northeast should be higher than the growth in consumption in the region. On the contrary, Brazil's installed capacity is expected to grow less than energy consumption.

In general terms the NEP estimates that by 2030 the total energy demand in Brazil will exceed 1000 TW h. The demand for hydropower will exceed 800 TW h, corresponding to approximately 77% of the total. The estimates of consumption (load) in Brazil indicate that there will be an average growth of 5% per year to 712 TW h in 2019. For the Northeast the evolution since 2006 appears in Table 4.

Table 4 shows the history of consumption for the period 2006 to 2010. According to this survey, in 2009 the Northeast Subsystem accounted for 16.8% of national consumption (388,204 GW h). The estimate for 2019 reflects an increase of 30.4% compared to 2010. In general, power consumption in Brazil in 2009 decreased 1.2% compared with 2008, driven by a 7.8% reduction in demand by Brazilian industries affected by the crisis.

In the Northeast in 2009 consumption increased only 0.2% compared with the previous year's consumption, but in 2010 there was a recovery and consumption in the region increased 8.8% compared to 2009, especially in the industrial sector, which increased by 7% and by the residential sector, which increased 12%, helped, according to the Empresa de Pesquisa Energética (EPE) [9], by healthy job market and the supply of credit, which encouraged the purchase of household appliances, resulting in additional electricity consumption.

It is estimated that by the year 2030 Brazil will exhaust the potential of its major rivers, requiring an urgent rethinking of energy alternatives to meet the growing demand for electricity in the country and especially in the Northeast Region.

Wind power emerges as a promising, and competitive option. In fact, at the last Reserve Auction 2009, sales were made at an average price of US$ 74.30/MW h. This trend was consolidated in the 2010 auctions, where energy from wind farms was contracted at an average price of US$ 65.52 per MW h.

This opens perspectives for increasing the use of wind power as a resource in the Northeast and also for attracting investment in the manufacture of wind turbines, enabling the region to establish itself as an industrial park in the wind energy sector [10].

In this context, the plan assumes that the demand for electric power would be fully satisfied by an increase in supply from different sources. However, the Brazilian system will continue to rely heavily on hydro-thermal sources of power.

National energy planning does not explicitly consider possible changes in climate such as precipitation, air temperature and the water flow of rivers, but ELETROBRAS included the impact of

[4] The Human Development Index (HDI) for the Northeast was: 0.652 (in 1995) and 0.720 (in 2005), the lowest in Brazil, where the average was.794 in 2005 [7].

**Table 4**
Evolution of the load (consumption) Energy in the Northeast from 2006 to 2019 (GW h).
**Source:** adapted from data from the EPE and the PDE 2019.

| Load | Background | | | | | Forecast | |
|---|---|---|---|---|---|---|---|
| | 2006 | 2007 | 2008 | 2009 | 2010 | 2014 | 2019 |
| Northeast | 60,558.85 | 63,480.55 | 65,732.73 | 65,859.50 | 70,993.00 | 72,372.00 | 92,561.00 |

climate changes in its strategic planning for the most probable scenario to the managed over the time horizon covered by the plan through 2030.

In the specific case of CHESF, it is important to map and assess climate risks that could threaten its performance and choose the path of adaptations that would contribute to confronting these impacts.

## 3. Climate risks and energy security

The risks of climate changes[5] can best be understood as the probability that they will occur and magnitude of the losses that may result. In the case of GCCs the probability is unknown, but the losses can be reasonably estimated.

These estimates are made under uncertainty[6] and according to Schaeffer et al. [6], it is essential to note that climate models are only approximate representations of very complex systems. The level of uncertainty related to the impact of the concentration of greenhouse gases on global climate, and the climate of Brazil in particular is great, when comparing results from different climate models developed by different research institutes.

It is assumed that, despite these uncertainties, the inclusion of climatic variables, altered by the GCCs predicted for this century, could contribute to national energy planning, without losses to consumers if these GCCs to do not occur.

The long-term energy security depends on current decisions about the volume of investment, choice of technology and research that can contribute to understanding the uncertainties about the future of hydroelectric power generation.

The Federal Government has been promoting new energy auctions from various different sources helping other vendors establish themselves in the market and adding to energy reserves. Some incentives have encouraged the development of new alternative energy projects, such as the guaranteed purchase of the energy generated, guaranteed long-term financing at attractive interest rates, and grants for research and technological development.

According to De Oliveira [13] energy security has two dimensions: the reliability and assurance of supply. Reliability refers to the system's ability to maintain energy supplies to the consumer market when faced with situations where, for reasons that are beyond the control of the companies, cost and energy supplies are necessary as a result of unpredictable natural phenomena or a system malfunction, whose effects are limited and short-term.

The guarantee of supply, again according to De Oliveira [13], refers to the protection against events that might require power cuts for extended periods, associated with failure to comply with rules or contracts by market participants.

For systems that extend over a vast territory in different river basins, the integration through transmission over the power grids could maximize operating scenarios under climate changes, short-term or seasonal—that are regionally distinct [14].

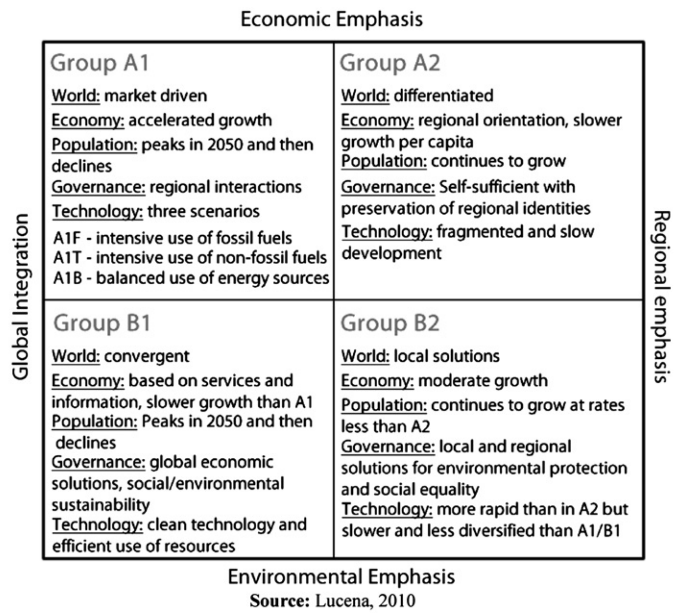


**Fig. 1.** Summary of the IPCC scenarios.
*Source*: [14]

Some studies, using scenarios from different forecasting models, can point to trends differing from those adopted by the IPCC (Intergovernmental Panel on Climate Change). In this study we chose to use the IPCC scenarios because of its broad acceptance by governments and various actors in the Brazilian economy.

The Brazilian energy system is vulnerable to climate change. The Northeast is the region most affected, both in hydropower production, due to the reduction of flow in the San Francisco River basin, as well as in the production of biodiesel and wind power [6].

According to Lucena [14], in the Special Report on Emissions Scenarios, published by the IPCC in 2000, 40 separate scenarios emerge that can be placed in four Groups (A1, A2, B1 and B2), which represent qualitative descriptions characterized by different paths with regard to economic, energy and environmental development.

The scenarios in the A2 and B2 Groups are more appropriate for regional studies, as shown in Fig. 1. The choice of these two groups of scenarios as a backdrop for the analysis of this work is based mainly on this feature.

The A2 scenario describes a heterogeneous world that emphasizes a regional orientation. In this scenario, economic interactions, and social and cultural differences between regions are less important, so that regions become more self-sufficient and tend to preserve their local identities. The per capita economic growth and technological development, in this scenario, proceed more slowly and are badly distributed, which does not help to bridge the gap between different parts of the world [14].

[5] This is a probabilistic concept, i.e., a function of the product of the probability of occurrence of an event the magnitude of its impact [11].
[6] The probability that an event will occur without knowing the likelihood. This is known in sociology, "subjective probability" [12].

The B2 scenario is less pessimistic, with fewer emissions. It assumes a world in which concerns about social and environmental sustainability are greater, where the world's population grows at a slower rate and economic development is more homogeneous than in the A2 scenario. But the introduction of technological innovation continues to be regionally heterogeneous [6].

Lucena [14], shows that the main basin of the hydroelectric development of the Northeast Region (São Francisco River), can be subject to large reductions of both firm energy[7] average energy,[8] in the scenarios A2 and B2 that the IPCC analyzed for the period 2005 to 2100. In the B2 scenario, for example, the basin would have 77% reduction in firm energy and the A2 scenario, there would be a reduction of 69%.

In [6], the river flows are reduced and the plants most affected are in the San Francisco Basin, which registered a fall of 23.4% in energy flow in the A2 scenario and 26.4% in the B2 scenario. The negative effects on average total power production by hydroelectric plants in Brazil of the decreases in average flow are confirmed, declining by 1% in the A2 scenario, and 2.2% in the B2 scenario. The effect was more pronounced in the São Francisco River plants, where production could fall by 7.7%.

CHESF holds several concessions for generation (9214 MW) and transmission (18,260 km) that must be renewed in 2015. The terms of these renovations are up to 35 years. It should be noted that the company already has contracts to supply energy running until 2046.

In this context, the expiration of concessions in 2015 causes some reflections on the future of the company. The effort to renew it would not make sense unless the company had a strategy to ensure the provision of essential public service to the population of the region. Although not explicit in their reports, it is assumed that investments in expanding the transmission network are designed to facilitate a greater volume of imports of energy from other regions, especially in the North, where the company already has a share in large project developments. Note that there was also a shift in its energy matrix, with the incorporation of wind power in its product mix.

It is obvious that the planning of CHESF includes strategies for the period of validity of contracts between 2040 and 2050, when the effects of climate change, according to studies cited, may be more intense.

We should now turn to consider environmental issues in the development of energy policies and energy sector activities, whether in pursuit of more sustainable forms of energy or in hopes of improved environmental performance by industrial operators [15].

We analyzed the strategies of the principal power generating company in the Northeast, CHESF, to assess the issues surrounding the economic implications resulting from the environmental impacts of climate change. This proposal is important because, as Jay [16] argues, there is undoubtedly an urgent need to apply the principles of environmental assessment to the large changes that are occurring in energy production. There are companies in which this is becoming not only accepted practice but part of their organizational culture.

## 4. Methodology

To identify the effects of global climate change on the CHESF's performance, the following tools were used as research methodologies: (i) a Panel of Experts, (ii) the Delphi Method, and (iii) a SWOT Matrix. The combined use of these three techniques enabled a further refinement of the issues pertinent to the study.

Using the Panel of Experts allowed us to identify the major internal and external variables to determine the relevant operating, financial-economic and environmental factors that could be used in predicting scenarios until the year 2050. The Delphi technique helped us to sort these variables by their importance and the SWOT method was used to construct the scenarios resulting from the combination of selected variables.

### 4.1. The panel of experts

To survey the variables technical meetings were held with a group formed by four experts in finance, energy, economy and environment, selected according to academic criteria (Masters and/or Doctorate) and experience (development of multi-disciplinary studies in these areas).

The interdisciplinary interaction dynamic adopted in the working sessions of the panel of experts was essential to ensure the consistency of the scientific study, since, as Terrados et al. [17] point out, the proposals and new ideas are subject to different scientific interpretations and/ or techniques.

During the panel sessions 24 variables (Table 5) were identified, classified according to the SWOT methodology and inserted into a questionnaire using the Delphi technique in order to capture the perceptions of experts about the importance of each of these variables to the future performance of CHESF.

### 4.2. Delphi method

In the survey, 14 experts responded to the questionnaire, which can be considered a reasonable number of respondents,

**Table 5**
Variables identified by the panel of experts.
**Source:** Authors.

| |
|---|
| **Environmental variables** |
| Precipitation[a] |
| Temperature[a] |
| Siltation |
| Water evaporation[a] |
| Water pollution (organic) |
| **Operational and market variables** |
| Average reservoir level |
| Installed capacity |
| Demand (increasing consumption) |
| Ability to expand generation |
| Efficiency (blackouts, technical losses) |
| Competitors in the region (absence/presence) |
| Investing in technology and innovation w/adaptation |
| Market position |
| Investments in transmission/generation expansion[b] |
| Public management restrictions |
| Regulatory issues (ANEEL, ANA[c]) |
| **Economic and financial variables** |
| Liquidity (ability to pay)[d] |
| Profitability (Net income) |
| Yield or % return on invested capital in the company |
| Level of indebtedness (volume of debt) |
| Cash from operations[e] |
| Dividends distributed (profits) to shareholders |
| Guaranteed revenue (sales contracts made) |
| Inflation, interest, cost of funds |

[a] Precipitation, evaporation and temperature influence the flow of water.
[b] Includes investment in operational efficiency.
[c] ANEEL (National Electric Energy Agency) and ANA (National Water Agency).
[d] Ability to pay short-term financial commitments.
[e] Ability to generate cash from normal business operations, namely its potential to generate wealth as a result of their operational characteristics.

[7] Firm Energy can be defined for a hydroelectric system as the largest amount of energy that can be obtained under the worst hydrological conditions, usually based on historical experience [14].

[8] Average Energy: is the highest amount of energy that can be produced assuming the average hydrological conditions of the series used in the simulation flow [14].

since, according to Vieira [18], an acceptable minimum group size is 10 people.

The questionnaire was structured to contain a brief account of the case study, information from respondents and a total of 38 questions divided into five Groups, using a Likert scale with scores from 1 (very low) to 5 (very high). In Group I the questions were designed to determine the perceived order of importance of environmental, operational and economic factors (15 questions) in Group II, the perceived order of importance of the Opportunities and Threats (10 questions) in Group 3, the questions were designed to determine the perception of the order of importance of the Strengths and Weaknesses (10 questions) in Group 4, the objective was to identify the perception of the impacts of GCMs on Corporate Sustainability (3 questions) and, finally, Group 5, contained the comments of the Experts (freely expressed).

At this stage of the study the Delphi method was applied, which according to Vieira [18], is designed to improve the use of expert opinion in forecasting trends on various subjects and try to get the most reliable consensus on the subject of study. Because it is a recognized group interaction process widely used in the social sciences [19], the Delphi method continues to be used and is a valid tool for forecasting and decision-making, according to Landeta [20].

This methodology consists of circulating the questionnaire several times, and examining the feedback from each round given by the experts on the results of the previous round, until a convergence of opinions, that is the group consensus emerges. Kayo and Securato [21] find that the Delphi method, as a predictor using various experts (opinion-makers or leaders), can play a key role in the process, especially in the construction of scenarios.

It can be argued that this method is especially recommended in the absence of quantitative data or when the data cannot be projected into the future with certainty, given the expectation of structural changes in the determinants of future trends, i.e., when there are disruptions or discontinuities in the environment or in specific subject that is being studied [22].

In the first round, the questionnaire was sent to the experts and their responses were analyzed using simple statistical analysis (mean, median, standard deviation, quartiles and variance) in order to remove the variables with low acceptability and classify the others in order of importance to form the SWOT matrix.

### 4.3. SWOT matrix

This type of analysis is often used in participatory planning approaches, although it was originally developed for strategic planning for business and marketing. It should be remembered that the SWOT analysis is only one tool and that it must be based on a thorough understanding of the situation and current trends [17].

According to Markovska et al. [23], the two main components of the SWOT matrix are the internal factors, described by Strengths and Weaknesses and the external environmental factors, described by Opportunities and Threats.

At this stage, the variables: siltation, water pollution, profitability and cash flow from operations were not selected by the group to make up a SWOT Matrix. The main reason for the limited acceptance of the first two was the existence of technological solutions to mitigate these problems. Profitability and cash generation were excluded because the group felt that an essential public service electric power will continue to be supplied even if the indexes are not satisfactory.

On that same occasion some variables were adjusted to absorb the group's interpretation of its various dimensions:

(a) Temperature, precipitation and evaporation of water were considered as components of water flow, which can increase (opportunity) or decrease (threat) in the future;

**Table 6**
Degree of importance of selected variables (Round 1).
**Source:** Authors.

| Opportunities | Ranking | Threats | Ranking |
|---|---|---|---|
| Investing in technology and innovation w/adaptation | 1 | Reduction in flow of water | 1 |
| Absence of competitors in the region | 3 | Limitations on public management | 2 |
| Meet growing demand | 2 | Unstable regulatory factors | 3 |
| Increased flow of water | 3 | Inflation, interest, cost of funds | 2 |
| Reservoir levels | 4 | Entry of competitors in the region | 4 |
| **Strengths** | **Ranking** | **Weaknesses** | **Ranking** |
| Market position | 3 | Relevant debt | 1 |
| Investment Transmission/ generation expansion | 2 | Hydro-electric sector stagnant | 2 |
| Dividend to shareholders | 4 | Low return on invested capital | 1 |
| Guaranteed revenue (sales contracts) | 1 | Modest liquidity | 3 |
| Reservoir levels | 2 | System failures and technical losses | 3 |

(b) Competition in the region may range from absence (opportunity) and entry of new competitors (threat);
(c) The reservoir levels (strength) may increase in future and further strengthen the company (opportunity);
(d) Installed capacity was considered a limiting factor in hydroelectric power generation, which is stagnant (weakness).

As a result, the variables accepted and adjusted as described above, resulted in the configuration shown in Table 6.

The results of the initial round were presented to the group that accepted the configuration and in the second round reached a consensus. The matrix was constructed from the rankings of scores, that attributed high (1st place) and very high (second place) rankings to the main variables. When two were tied, both were retained.

Therefore, in the Opportunity quadrant, "Investing in Innovation for adaptation" took first place with 86% of the respondents attributing high and very high importance for this variable. Second, 57% of the respondents selected "Meeting increasing demand." In the Threats quadrant selected by 64% of the experts, "Reduction of the flow of water" was most important. In this quadrant there was a tie for second place among "Limitations on Public Management" and "Inflation, interest and cost of financial resources", with 43% of the respondents attributing high and very high importance to these factors. There was a tie for second place in the Strengths quadrant between "Reservoir Levels" and "Investment in Transmission and Generation Expansion" (50% each), but in first place, for 71% of the respondents, was "Guaranteed Income (from sales contracts)."

The Weakness quadrant resulted in a tie for first place, with 64% of experts choosing the most important variables as "Relevant debt" and "Low return on invested capital", leaving stagnation and hydroelectric power generation, selected by 29% of experts, in second place.

As a result of the application of methodologies developed in this step, the SWOT matrix, composed by the selection of the most important variables by consensus, appears as shown in Table 7.

## 5. Analysis of results

The methodology we used allowed us to project four different scenarios: two for the extreme scenarios (I and IV) and two

**Table 7**
Expected to CHESF SWOT matrix.
**Source**: Authors.

| CHESF matrix | Strengths | | | Weaknesses | | |
|---|---|---|---|---|---|---|
| | Guaranteed revenue | Investment generation/ transmission | Reservoir levels | Debt | Return on capital | Generation stagnant |
| Opportunities<br>Investing in innovation for adaptation<br>Growing demand | Scenario I—Development | | | Scenario II—Growth | | |
| Threats<br>Reduction in flow of water<br>Limitations on public management<br>Inflation, interest, cost of funds | Scenario III—Survival | | | Scenario IV—Decline | | |

intermediate scenarios (II and III). All of these scenarios were analyzed based on the characteristics of the region, the company and its financial-economic and operating variables.

### 5.1. Scenario I

Combining Strengths and Opportunities resulted in Scenario I in which the Development of the company prevails. In this context, the company uses its operating strengths to take maximum advantage of opportunities.

In this scenario, the level of the reservoirs would store energy and serve to support the long-term sales contracts, with guaranteed revenues. Investments in the generation and transmission of energy would permit us to infer that CHESF would be able to meet the growing demand expected in the Northeast Region. Perceiving the opportunity to innovate and adapt to climate change can opened the way for technological advances in renewable energy and offer opportunities for new revenue streams.

Scenario I, which represents a situation for Development in the face of Climate Change, shows that the behavior of the selected variables favors the company's future situation. In this scenario, the expectations for Opportunities (Innovation and Adaptation, and Growing Demand) and Strengths (Investment in Generation and Transmission, Guaranteed Revenues, Reservoir Levels, the latter less sharply) are increasing. Presumably, then, the changes in the strategic planning will occur at different times, as suggested by the trends, enabling the implementation of pro-active decisions.

Even with the depletion of the hydraulic potential of the São Francisco Basin, revenues should rise due to and increase in demand because of pressure from higher energy consumption in the production sectors and for cooling buildings, as a result of the possible increase in average temperature in the region.

To meet this growing demand the company must make significant investments in technological innovation, seeking to deploy energy from renewable sources such as eolic, photovoltaic or biomass in the geographic region in which it operates as well as expanding its transmission network.

The innovations should meet the criteria of technical, environmental and economic feasibility, and should not lead to a sharp increase in the rates paid by consumers. It should be noted that the variable "Investment in Innovation for Adaptation" was considered the most important by 86% of the experts, ahead of all other all other factors.

### 5.2. Scenario II

In case of Scenario II (Opportunities vs Weaknesses), the behavior of the selected variables indicates that in the future the company should grow because of the opportunities that the external environment will provide. The expectation is that although the opportunities are increasing (Adaptation and Innovation for Growing Demand), the threats (Stagnant Electric Power Generation and Relevant Debt), will be even more pronounced. The low return on capital (Threat) remains stagnant, with a slight tendency to decline even further. Therefore, the increased demand for innovation and opportunity will not be properly exploited, due to operating and economic-financial weaknesses.

The generation of hydroelectricity cannot be increased except for the use of a few Small Hydro Power plants (SHP), with limited generating potential. In this case, to meet the demand, the company is forced to buy power in order not to default on its contractual obligations and is therefore subject to variations in market prices.

The opportunity to meet the increased demand with new sources of generation would be postponed, since investments in innovation would be postponed and funded with capital from third parties, subject to interest on short and long term.

The increase in debt encumbers the results and hinders the return on invested capital. In addition, payment of principal and interest debt could impact the cash flow and reduce the investment capacity of the company.

In this growth scenario, the enterprise would still be profitable, but the rate of return for investors would become unattractive compared with other opportunities in domestic and international markets. In the end, the situation would not be comfortable, despite the opportunities that exist.

### 5.3. Scenario III

Scenario III reflects how the Threats, faced with the Strengths, could change the situation of the company in the future. The most important Threats are: Reduction in flows, Limitations on Public Management and Inflation, Interest and cost of funds.

In this scenario, defined as Survival, we estimate some increasing Threats (Limitations on Public Management and Inflation, Interest and Cost of Financial Resources) and slightly decreasing Strengths (Reservoir levels, Guaranteed Income, and Investment for Generation and Transmission), which should decrease, but less than inflation. Water Flow Reduction (Threat), caused by the GCCs would also be more severe, affect the level of the reservoirs and thus the levels of guaranteed revenue. The company may lose contracts since participation in the auctions conducted by the Federal Government require proven capacity to generate energy. However, the transmission revenue could be preserved as long as investments were made in the network to prevent system failures.

A slowdown due to the reduction in revenues could reduce the pace of investment and further aggravate the situation. It may be necessary to resort to raising capital by paying the highest

interest rates in the world, charged in Brazil with strong signs that average interest rates will continue to rise in an attempt to control inflation.

The governance of the company is public, carried out by the parent company, which sets general guidelines and coordinates the implementation of Federal Government policies. In addition, the company is subject to regulation and supervision by the National System Operator (ONS), the National Water Agency (ANA) and National Electric Energy Agency (ANEEL). The constraints on management range from delays in decisions from superiors to differences in the various standards that must be met. The various levels of decision-making can become a complicating factor for both operating and financial situations.

Public management can also have a positive impact for the company as it would be able to receive funds from the parent company in the form of capital increases, but this would not be a permanent solution to the problem.

In this scenario the company would seek to use its Strengths to confront the Threats, especially those from climate change. All efforts would be directed to ensure the Company's survival in the face of variables that it cannot directly control.

The fact that the company has already installed production sites could make it more competitive, enabling lower prices at the auctions. It could also use its knowledge of the business to increase investments in energy transmission, which would become the predominant activity, if the level of the reservoirs and turbines were severely affected by reduced flow of water.

### 5.4. Scenario IV

Threats that appear in the SWOT matrix can lead CHESF to an even more unfavorable scenario, when faced with its Weaknesses. Scenario IV, which represent the most critical and damaging expectations for the company, projects increasing Threats (Limitations on Public Management and Inflation, Interest, Cost of Financial Resources) and worsening the company's Weaknesses (Low Return on Invested Capital and Hydro-Generation Stalled and Relevant Indebtedness).

In this Scenario of Decline there would be a dangerous combination of environmental, operational and financial problems. The relevance of the debt would further weaken liquidity and profitability ratios. The return on invested capital could escalate and even become negative. The effects of GCCs would be intense and the cost of mitigation would be greater than the cost of adaptation. With interest and inflation rising, the situation of the company would continue to deteriorate, partly because in these conditions to obtain credit in the market would become increasingly difficult.

Problems arising from hydroelectric generation due to reduced flow and the depletion of the hydroelectric potential of the region, could lead to problems in other SIN submarkets that are responsible for supplying the extra energy demanded in the Northeast. Investment would be needed to reduce failures and technical losses of the transmission system, as well as to expand in order to ensure imports of energy over long distances.

Without investments in innovative technologies, the company could lose its position in the market to new competitors, turn delinquent in its contractual obligations and suffer penalties imposed by agencies responsible for control and supervision of the SIN.

The public management, with multiple levels of decision-making could be slow in responding to the impact of external variables on internal ones. Response actions would be slow, with neither the efficiency nor the effectiveness required by highly complex problems.

Finally, the worsening situation of the company could cause it to decline if it were not possible to immediately start negotiations with decision makers, persuading them that postponing the inclusion of GCCs in strategic planning will increase the risk of deficit and reduce the reliability of the entire power supply system in the region.

## 6. Conclusion

The vulnerability of businesses and citizens is what makes the regional and global economic systems become vulnerable. Corporations are economic units that are exposed to risks and uncertainties. These risks and uncertainties are not always adequately measured by the management of these companies. In the case of hydroelectric power companies, risk management can guarantee a safe supply of electricity to the region's sustainable development.

However, the control and management of these risks must be preceded by the identification and measurement of the risks and uncertainties. With this in mind, this study managed to map twenty-four environmental, economic, financial and operating variables that can be affected by climate change on the survey horizon.

The use of the SWOT matrix served as a research methodology as a tool for the analysis of the effects of climate change on the overall situation of companies in the generation and transmission of electricity, in the particular a case study of CHESF, helping to shift the focus discussion from the global to the company level.

The analysis of scenarios resulting from different combinations of these variables led us to conclude that for the case analyzed, the corporate vulnerability of CHESF could have a negative impact negatively on its performance in the regional energy market.

Among the most important vulnerabilities, we can highlight the potential difficulty of making substantial investments to increase its capacity to generate energy from alternative sources. This difficulty will be even more pronounced if there is no change in the dividend policy in place today. It is essential that a Revenue Reserve Fund be created for investments that would separate a significant portion of annual earnings to proactively implement actions to adjust to climate change.

CHESF, whose main revenue source is hydroelectric power, depends heavily on climate issues to support its development. In the different scenarios for its performance through 2050, it became clear that t would need to invest in innovative technologies to adapt to the impacts that climate change could have on water resources.

A possible adaptation would be the use of the energy potential of wind, sun, ocean waves and tidal changes, as these natural resources are abundant in the region. The potential for power generation through biomass waste and other waste such as sugar cane bagasse should not be ruled out.

The deployment of small tidal power plants for harnessing the energy potential of the sea, with tidal energy generators to generate electricity from both directions of the flow of water could also be an interesting option for the company.

The potential energy of the winds in the region also could be better utilized to complement hydro generation during the dry seasons. The installation of wind farms in different locations can consolidate some CHESF initiatives already running in association with other companies in the region.

As the region has a high degree of sunshine throughout the year, the creation of solar energy plants could be an attractive option. The feasibility of technologies for production and storage of this energy depends on the behavior of their costs. Technological development in the long run can reduce the size of the area occupied by solar generation plants as well as costs of installation and maintenance. Efficiency needs to be improved. The use of

concentrators of solar energy is very promising in this regard. In this particular case, investment in research and innovation is highly recommended.

Exploiting the potential for generating electricity from biomass must combine the availability and cost of waste transport. This option could provide a solution to the problem of disposal of solid waste that afflicts local governments.

The installation of more alternative energy sourced plants seems to be an unavoidable decision for the electricity sector. The installation of these plants in the Northeast depends on policies to encourage private investment and public investment programs committed to the generation of electricity, especially when using less dependent on sources of water. CHESF in order to ensure its market position and reduce the possibility of entry of new players, could lead this process of transition from the current electric power mix to a mix of renewable energy sources and alternatives, more robust and less dependent on hydrology cycles.

Future research could improve on the results of this study, expanding the database, the amount of expertise and regions of the country. It would be also possible to use information for extended periods and in various types of computer modeling appropriate for this purpose. This would enable the development of a method useful for qualitative and quantitative analysis of business risks from climate change.

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